

## Short communication

## Validation of an indirect data collection method to assess airport pavement condition

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## ABSTRACT

In this study the authors compare two methods for airport asphalt pavement distress data collection applied on the main runway of Amílcar Cabral international airport, located at Sal Island in Cape Verde. The two methods used for testing were traditional visual inspection (on-foot) and an indirect method using a vehicle equipped with image capture and recording, lasers and geolocation devices (in-vehicle inspection). The aim of this research is to contribute to the validation of the proposed low-cost in-vehicle pavement distress inspection system with semiautomatic data processing in order to be considered in the implementation of the pavement condition assessment component of airport pavement management systems (APMS). This is a particularly important component as from the collected distress data it is possible to assess the condition of the pavements and define intervention strategies. Validation of the indirect data collection method is evaluated by statistical comparison of the collected distress data and pavement condition index (PCI) obtained from both methods. Statistically non-significant differences between the result sets validate the proposed indirect method, however the analysis evidenced two aspects that need improvement in the proposed system, namely the quality of the captured images to identify distresses with lower severity level and inspector training for proper allocation of severity levels during image analysis. This results in significant advantages considering that the total amount of the runway pavement area is inspected. Inspection time is reduced and data collection cost can be reduced. Processing and results visualization on GIS environment allows revaluation of the dataset on the in-vehicle method. Data interpretation and measurements quality control becomes simpler and faster.

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## 1. Introduction

The development and implementation of an APMS makes it possible to manage assets in a practical and sustainable manner, assisting management personnel in decision making through priority setting, cost quantification and activity scheduling, resulting in the development of economically viable strategies for pavement maintenance [1–3]. Fig. 1 presents the main components that are considered on the implementation of an APMS to operate at the network or project level [4].

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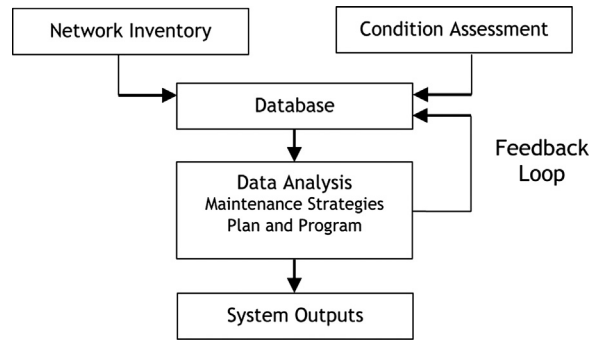


Fig. 1. Main components of an APMS [5].

Information related to the characteristics of the airport pavement network, as construction, maintenance, traffic and condition data are collected in the network inventory component. In condition assessment, condition data, defined accordingly to the evaluation method and survey frequency adopted by the supervising agency, is used to determine the pavement condition. Data is organized and stored in a database for use in data analysis, where evaluation and prioritization of the rehabilitation and budget needs over the analysis period is performed. Finally, the main outputs (results of the analyses) are organized in different formats for consideration of engineers and managers.

The feedback loop, often overlooked, establishes a process where actual performance and cost data are inputted back into the models used on pavement management analyses [4].

From the above, it is possible to conclude that efficient airport management needs a significant amount of data regarding the condition of airport pavements. Quality of the collected data is therefore essential to identify deficiencies and properly diagnose pavement condition. This allows to detect current and future maintenance needs predicting the effects of intervention strategy over pavements' lifetime [6,7].

Data is generally collected by visual inspection of airport pavements. However, visual collection of surface distresses is becoming increasingly challenging for airport maintenance teams as operational constraints limit access time for inspections on high priority pavements. Moreover reductions in funding and operational staff resources lead to visual inspection constraints [8]. Consequently, choosing the data collection method that will provide the necessary information to evaluate the condition of pavements is vital for APMS success.

Data collection by visual inspection has evolved from the traditional visual condition survey performed on foot, where distress type, severity, and quantity are identified and recorded in paper form, to the use of multifunctional vehicles. Data collection systems installed on these vehicles are composed by one or more acquisition devices and post-processing applications for semiautomatic or automated data extraction procedures, based on computer vision and image processing algorithms [9]. Devices are generally used both on road and airport environments. Among the most common, those standing out are GNSS (location referencing) and video logging modules (for pavements and 360° imagery), laser crack and rut measurement system (cracks, transverse profile and rutting), high resolution odometer (linear distance), laser profilometer (roughness – IRI, macrotexture and longitudinal profile) and land mobile light detection and ranging (LiDAR) systems. Several referenced authors tested, discussed and used data obtained by these modules and systems on airport pavement inspection [8,10–12].

Also important to notice is the latest developments in road and airport asset inspection technology, that focus on the use of unmanned aerial vehicle (UAVs - drones) including LiDAR technology [13–15].

In this context, an in-vehicle system with image capture and recording, lasers and geolocation devices that can be classified as a low-cost, mobile multifunction system with semiautomatic data processing is proposed. This in-vehicle approach has been developed over the last 4 years at the department of civil engineering and architecture of the University of Beira Interior (UBI) [5,16–22], aiming to improve the efficiency of data collection at local and small international airports. So, this study aims to verify the effectiveness of the indirect in-vehicle inspection method, that '*à priori*' seems to be a more practical methodology to use as it requires less time on the runway and fewer resources than on-foot inspection (without the aid of specialized technical apparatus).

For this purpose, results obtained from a traditional on-foot pavement surface distress inspection and the proposed in-vehicle inspection system developed at UBI are compared. A comparative statistical analysis was performed on the results of pavement surface distress data (type, severity levels and densities) collected at exactly the same sampling units of the main runway of Amílcar Cabral international airport (ICAO: GVAC), located at Sal Island in Cape Verde.

The pavement condition index (PCI) obtained by Lima (2016) [21] for both methods is also compared. PCI for airport pavements was developed by the US Army Corps of Engineers through funding provided by the U.S. Air Force. This index describes the structural integrity and operational condition of pavements and its determination is based on the identification and assessment of the severity level of 17 distresses observed on pavements surfaces [23]. It ranges from 0 (worst condition) to 100 (best condition) and its rating scale can be related to maintenance and rehabilitation activities [2,3,12,20].

This paper is organized in 5 sections: the first section presents the concept of APMS and the importance of choosing the airport pavement inspection technology for the success of the pavement condition assessment; the following three sections describe the statistical approach adopted to validate the indirect pavement data collection method tested, present the case study and the statistical analysis results; finally, the last section concludes highlighting some reflections of the authors based on the results obtained and presenting topics for further discussion.

## 2. Methodology

To validate the proposed indirect data collection method (in-vehicle), the collected distress data and PCI values obtained through on foot and in-vehicle inspection were statistically compared.

Statistical comparison of groups depends on how the variables under study are measured (qualitative / quantitative), its quality and quantity, type of sampling (probabilistic or random / non-probabilistic or non-random), relationship between samples (independent/paired), the samples' normality distribution (normal/non-normal) and the number of groups to be compared.

In this study, variables referring to pavement distress type, severity and density were evaluated on samples from the GVAC runway 01–19 (study population). Sampling was defined according to ASTM D5340-12 [23]. This standard adopts systematic random sampling for selection of sample units to be inspected for pavement condition assessment.

Since the study compares both pavement inspection methods, paired samples constituted by the same subjects were considered (comparison of two-paired groups), so pavement distress data was collected using the two inspection methods on the exactly same sampling units of the runway.

Statistical comparison of the samples is then evaluated by statistical tests. Test choice depends fundamentally on the number of groups to be compared and on normality of the data (variables), assessed by the Kolmogorov-Smirnov and Shapiro-Wilks tests.

Variables with normal distribution are statistically analysed by parametric *t*-test, while those with non-normal distribution are evaluated using the Wilcoxon non-parametric test [24]. *t*-test is used to determine the occurrence of a significant difference between the means of two-paired groups. On the Wilcoxon test, differences between sets of pairs are calculated and analyzed in order to establish if the two groups are statistically significantly different [24].

## 3. Case study

The case study was developed at runway 01–19 of the Amílcar Cabral international airport (ICAO: GVAC), located about three kilometres south of the city of Espargos, at Sal Island, Cape Verde. Cape Verde's airport system consists of seven airport infrastructures. It is the main driver of the Cape Verdean economy as the country main activity is tourism. In addition, the geography of the territory, an archipelago, contributes to the increased relevance of air transport. Issues such as accessibility between islands and to other countries becomes a central demand for the economic development and social activity of citizens.

For distress inspection, the airport pavement network is divided into 4 branches with a total of 16 sections. GVAC's runway is 45 m wide by 3000 m long, with 7.5 m wide shoulders, comprising 3 of the aforementioned sections with 270 sampling units. The entire surface of the runway pavement was inspected by the in-vehicle system (270 sampling units) and 43 were inspected on foot. This 43 sampling units constitutes the minimum number to be inspected according to ASTM D5340-12 for PCI evaluation [20]. Table 1 summarizes the segmentation and adopted coding information.

**Table 1**  
Coding and segmentation of GVAC runway 01–19.

Pavement	Code	Description/Comments
Pavement network – Airport	SID	GVAC pavement network
Pavement branches	R01	Main runway (01–19)
	TWY	Taxiway
	BER	Shoulders
	APR	Apron
R01 pavement sections	A	900 m measured from end 01 (touchdown area)
	B	1200 m located in the central part of the runway
	C	900 m measured from end 19 (touchdown area)
Pavement sampling units – total runway area (segmentation according to ASTM D5340-12 sample area criteria)	A: 81 sampling units	500 m <sup>2</sup> sampling units (100 m by 5 m)
	B: 108 sampling units	In-vehicle visual inspection
	C: 81 sampling units	
Pavement sampling units – sample area for inspection (minimum area to inspect according to ASTM D5340-12)	A: 14 sampling units	500 m <sup>2</sup> sampling units (100 m by 5 m)
	B: 15 sampling units	Traditional and in-vehicle visual inspection
	C: 14 sampling units	

It should be noted that despite having performed a total runway in-vehicle inspection, only the common 43 sampling units were used on the comparative statistical analysis. Fig. 2 presents the location of the 3 pavement sections studied.

On the in-vehicle inspection the following pavement distresses are directly identified on daytime images: alligator cracking; bleeding; block cracking; jet-blast erosion; joint reflection cracking; longitudinal and transverse cracking; oil spillage; patching and utility cut patch; polished aggregate; ravelling; shoving; slippage cracking and weathering. Laser-line projection images captured at night allows the identification of corrugation, rutting, swelling and depression distresses. These 17 distresses are the ones considered in ASTM D5340-12 standard for PCI calculation. A detailed description, as well as the definition of severity levels (low, medium and high) and how to measure distresses can be consulted in [23,25].

Thus, in order to collect all the distress data, two in-vehicle inspections were carried out, one during the daytime and the other at night. Taking into account the access restrictions to the runway due to aircraft traffic, all information for the complete runway was collected within 3 days, while the on-foot inspection took 3 weeks for only 43 sampling units.

Upon completion of both inspections, a georeferenced data set of images was obtained and processed for visualization on a geographic information system (GIS). Images were collected to form a continuous stream with enough resolution to allow a spatial resolution of less than 0.003 m per pixel at the centre of the image and reducing spatial resolution towards the margins due to geometric distortion associated with the optical system. Later the images were correlated with positioning data gathered on a dual band GPS receiver and post-processed on a PPP (precise point positioning) strategy using online free processing resources. This allowed for location errors far below 0.05 m while maintaining equipment to a minimum. Image and positioning data correlation quality was verified using control points on the ground. Image georeferencing and orientation was performed using an in-house developed software package.

Image visualization occurs on a continuous coverage over imposed reference features of the runway topographic survey. This visualization allowed identification of surface pavement distresses and severity level as well as measurement of areas and length of influence. The on-screen digitisation process of distresses length and area from captured images allows for a vertex placement accuracy that is, on average, of 2 pixels, corresponding to 0.006 m. Measurements performed on-foot using measuring wheel presents a sub-decimetric accuracy for linear distresses. Surface distress area is calculated using the product of two approximately orthogonal linear measurements. Consequently, measurement of areas using images, based on careful, on-screen raster to vector digitisation, are more accurate than *in situ* measurements using a measuring wheel.

The inspections identified the presence of 6 types of pavement distresses on GVAC runway. A comparative analysis of the data obtained by the two inspection approaches shows a discrepancy regarding the amount of identified distress types and density by severity level (see Table 2).

While 6 distresses were identified by on-foot inspection only 4 were registered using the in-vehicle system. The two distresses not identified during the in-vehicle inspection present essentially a low density and severity level on the on-foot inspection. In the case of depressions, only a low level of severity was identified on-foot, which is thought to have impaired identification using the in-vehicle system as it is difficult to detect this level of severity on the captured images. For longitudinal and transverse cracking at low severity level, the same situation occurs, however it is possible that a misidentification occurred at high severity level, probably on areas presenting alligator cracking. Previous tests of the in-vehicle system on road environment successfully identified cracking situations at a high severity level [22].

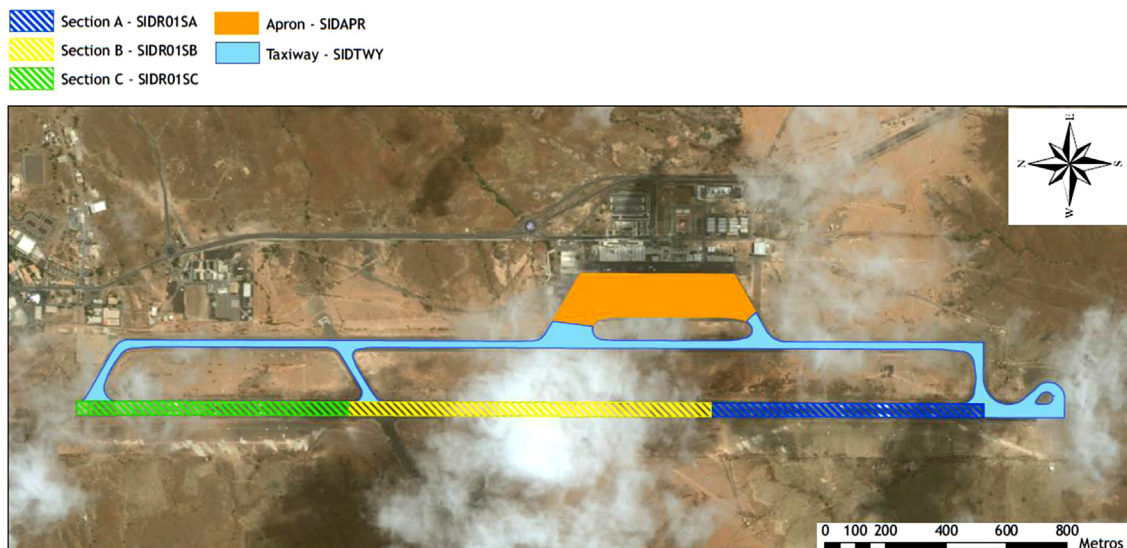


Fig. 2. Amílcar Cabral International Airport runway section division.

**Table 2**

Identified pavement distresses and densities by severity level and type of inspection.

Inspection type and identified distresses	Density by severity level (%)*		
<b>On-foot inspection</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>
Alligator cracking	2.00	1.83	0.07
Patching and utility cut patch	2.18	1.02	1.92
Ravelling	0.70	2.66	11.13
Weathering in surface wear - dense mix asphalt	4.78	7.82	16.00
Depressions	0.53	0.00	0.00
Longitudinal and transverse cracking	0.24	0.00	0.16
Sum (all distresses identified): 53.04	10.43	13.33	29.28
Sum (distresses identified on both methods): 52.11	9.66	13.33	29.12
<b>In-vehicle inspection</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>
Alligator cracking	1.09	2.23	0.00
Patching and utility cut patch	0.10	2.35	1.15
Ravelling	0.00	2.75	12.60
Weathering in surface wear - dense mix asphalt	1.96	3.26	23.39
Sum (identified distresses): 50.88	3.15	10.59	37.14

Severity level density distribution shows a bias towards the higher severity class on distresses collected by the in-vehicle system. However, the sum of common distresses densities for both methods is similar. To assess whether these differences are statistically significant, a statistical comparison of the two groups of samples was performed.

It is worth to point out that data processing of the information gathered during the two inspection methods was performed by the same inspector.

Subsequently and considering the 6 (on-foot inspection) and 4 (in-vehicle inspection) identified stresses, PCI values were calculated per inspected sampling unit and pavement section for both methods (see Table 3 and Fig. 3). Values obtained by both approaches are similar, with most of the results showing PCI values in the range 25–40, reflecting the need for a short term intervention on the runway pavement.

Fig. 3 presents the scatter plot of PCI values paired by sampling unit and the corresponding linear regression model. The linear model is a good fit for the data, as differences between observations and the predicted values are small and unbiased (fitted values are not systematically too high nor too low in the observation space). These conclusions are emphasized by a  $R^2$ -value of 0.8993 and a standard error of the estimates of 3.6386.

Considering an optimal model where in-vehicle PCI would be the same as on-foot determined PCI, represented on Fig. 3 as a reference line, it is clear that lower PCI values are overestimated on the in-vehicle approach and higher values are underestimated, with a pivoting point around PCI=32.

#### 4. Statistical analysis and discussion of results

Density values of 4 pavement distresses that were identified on GVAC's runway by on-foot and proposed in-vehicle inspection system were used to statistically compare the two inspection approaches. This was also performed for the PCI values obtained from those identified distresses.

For this purpose, three analyses were implemented: descriptive statistical analysis considering dispersion and central tendency measures, a normality analysis to determine the comparative statistical test to be applied during the comparative study (parametric or nonparametric) and a statistical comparative analysis.

On the normality analysis the Kolmogorov-Smirnov and Shapiro-Wilk tests were adopted and applied to density values by type of distress and level of severity (low, medium and high). The obtained P-values indicate that both data sets (on-foot and in-vehicle) essentially present a non-normal distribution ( $p$ -value  $< 0.05$ ). The exception being weathering in surface wear (high severity level) on in-vehicle inspection that exhibits a normal distribution according to the Kolmogorov-Smirnov test. This result can be related to the higher number of identified cases when compared to the other 3 distresses (larger sample size), suggesting an influence on the result of the normality test (see Tables 2 and 4). Due to the non-normal

**Table 3**

PCI values obtained for each sample unit inspected and runway section (adapted from [21]).

Section	Type of inspection	PCI per sampling unit	PCI per section
A	On-foot	36, 38, 41, 43, 52, 20, 52, 27, 34, 46, 24, 11, 60, 46	38
	In-vehicle	30, 40, 45, 40, 52, 22, 46, 30, 37, 46, 26, 15, 54, 48	38
B	On-foot	22, 32, 48, 25, 22, 15, 17, 18, 27, 56, 38, 53, 31, 35, 20	30
	In-vehicle	26, 26, 41, 27, 28, 24, 18, 16, 30, 59, 38, 47, 31, 29, 25	31
C	On-foot	44, 27, 32, 36, 35, 20, 35, 63, 32, 43, 59, 25, 30, 26	36
	In-vehicle	47, 23, 32, 32, 29, 19, 35, 53, 32, 39, 54, 29, 24, 28	34



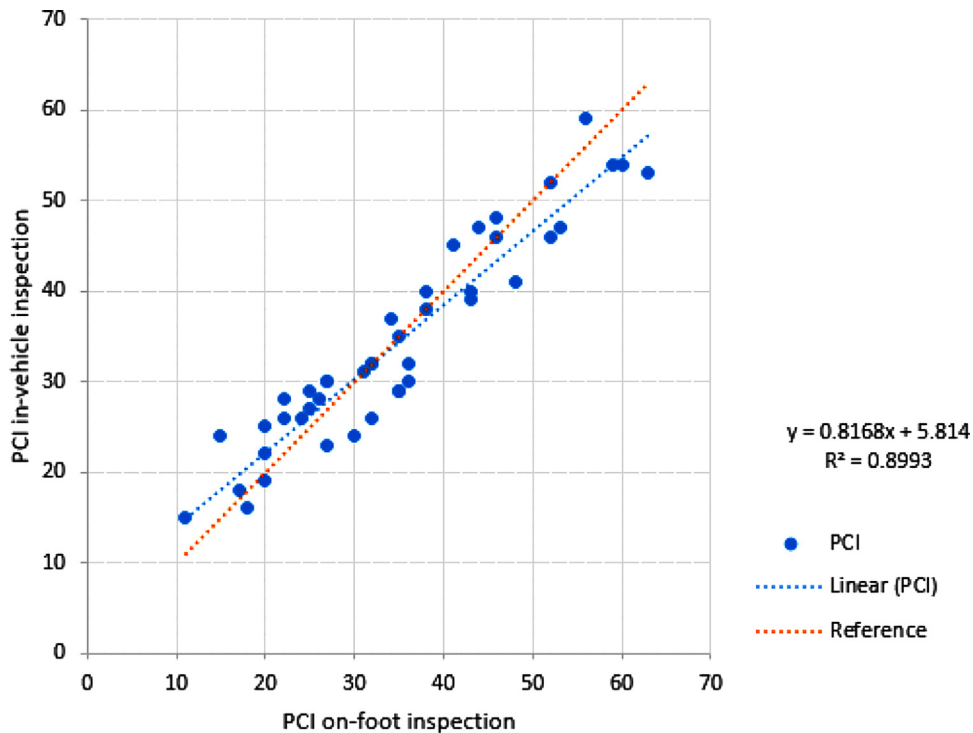


Fig. 3. Paired values of PCI obtained in the two inspections (on-foot and in-vehicle) and linear trend line.

distribution of the distress density data, the non-parametric Wilcoxon test was adopted for comparative analysis of both groups.

Considering PCI values, the Shapiro-Wilk normality test indicates a normal distribution of data ( $P$ -value > 0.05) for both on-foot and in-vehicle inspection. However, according to the Kolmogorov-Smirnov test, PCI values obtained from in-vehicle inspection data do not follow a normal distribution. Given these results, a PCI statistical comparison with parametric t-test (statistical mean) and nonparametric Wilcoxon test was performed. An f-test was also performed to compare sample variance.

Results of the normality tests and the statistical comparison analysis are presented in Tables 4 and 5.

Results show that patching and utility cut patch distress identified at low and medium severity levels were not validated. In these cases,  $P$ -values are less than 0.05, meaning that the samples are non-comparable. The same occurs for weathering in surface wear at high severity level and it can be related to the discrepancy of the normality results observed for this particular case.

The non-validation of these cases can be related to classification difficulties of weathering in surface wear at a specific severity level on collected images, as well as other pavement distresses presenting low severity level.

**Table 4**  
Normality tests results.

Test	Kolmogorov-Smirnov P-value			Shapiro-Wilk P-value		
<b>Inspection by foot Severity level</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>
Alligator cracking	0.000	0.000	0.000	0.000	0.000	0.000
Patching and utility cut patch	0.000	0.000	0.000	0.000	0.000	0.000
Ravelling	0.000	0.000	0.000	0.000	0.000	0.000
Weathering in surface wear - dense mix asphalt	0.000	0.000	0.011	0.000	0.000	0.000
PCI	0.200			0.340		
<b>In-vehicle inspection Severity level</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>
Alligator cracking	0.000	0.000	*	0.000	0.000	*
Patching and utility cut patch	0.000	0.000	0.000	0.000	0.000	0.000
Ravelling	*	0.000	0.000	*	0.000	0.000
Weathering in surface wear - dense mix asphalt	0.000	0.000	0.200	0.000	0.000	0.002
PCI	0.008			0.097		

\* Severity level not observed in the data set.

**Table 5**Wilcoxon test, *t*-test and *f*-test results.

Variable	Wilcoxon test P-value			<i>t</i> -test P-value	<i>f</i> -test P-value
<b>Severity level</b>	<b>Low</b>	<b>Medium</b>	<b>High</b>	Not applicable	Not applicable
Alligator cracking	0.068	0.657	0.317		
Patching and utility cut patch	0.012	0.011	0.076		
Ravelling	0.068	0.861	0.640		
Weathering in surface wear - dense mix asphalt	0.114	0.122	0.008		
PCI	0.273			0.4025	0.3372

The remaining distresses-severity pairs and PCI values were validated by the Wilcoxon test. *t*-test also validated PCI values.

Based on the results of *t*-test (statistical mean) and *f*-test (variance), it can be inferred that the use of the proposed in-vehicle system to inspect pavement surface distresses did not significantly influence PCI results, since the statistical average (*t*-test) of both samples, as well as its variance (*f*-test) produced P-values greater than 0.05, validating the proposed in-vehicle system.

## 5. Conclusions

The comparative statistical analysis on PCI values validates the innovative low-cost method proposed for carrying out inspections using an equipped vehicle. For a more consistent validation, distresses identified in both approaches were also meticulously analysed by level of severity.

Data analysis evidenced a better identification of distresses and severity levels by direct visualization, in particular for low severity levels and weathering in surface wear distress.

Comparing the type of distresses identified by each approach, it's clear that the in-vehicle method could not assess two types of distresses that were surveyed on-foot at a low severity level and low density values. Still, by comparing distresses allocation by severity level, it's clear that a tendency to classify distresses at higher severity level occurs on the in-vehicle system.

These results, supported by the statistical comparison analysis, do not compromise the proposed method, since it allowed to identify improvement aspects in the proposed in-vehicle system and in the semi-automatic processing of images.

The authors consider that, by improving the in-vehicle system, the difficulties encountered while identifying some distresses will be surpassed. This improvement can be achieved through the use of higher image quality cameras and the addition of a second camera placed to capture pavement roughness and small deformations. It is further considered that inspectors training on image analysis, especially regarding distress severity level allocation, as well as the inspectors' accumulated experience could positively influence results of the comparative statistical analysis.

By comparing both inspection approaches it was noticed that the proposed in-vehicle prototype with image, laser and GNSS devices has as the main advantage the reduction of the time needed to collect pavement distress information, as traditional (on-foot) surveys are time consuming, becoming more expensive for larger airports with traffic constraints.

The in-vehicle approach also allows to continuously survey the condition of the entire pavement surface and to process all the information at the office visualizing data on a GIS environment, allowing re-evaluation and confirmation, if necessary, of the pavement distress data obtained under the same conditions as those verified at the time of inspection (image archive).

With this approach it is also possible to compare the GIS image and alphanumeric data from several inspections carried out over the pavement lifetime, supporting trend studies of pavement condition.

## Declaration of Competing Interest

The authors report no declarations of interest.

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